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INITIAL OBSERVATIONS ON PERCEPTUAL RESPONSES AND DISTURBANCE PRODUCED BY THE VERTIFUGE

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Perceptions of pitch and ratings of disturbance were obtained from six subjects with the Dynasim's Vertifuge cockpit configured in the centripetal heading. Verbal descriptions of transient responses during change in pitch followed expectations based on the combination of angular accelerations, cross-coupled angular accelerations, and resultant linear accelerations occurring during the transient phase of stimuli. Magnitude ratings of pitch during the steady-state phase of stimuli suggested the presence of adaptation effects that alter perceptions according to the order of the stimuli used. Further experimentation is needed to establish the significance of adaptation effects. Mean settings of the "visual horizontal" were fairly well predicted by the angle of the resultant of gravity and the centripetal vector calculated at the radial distance of the head from the center of rotation. Despite large "pitch-up" perceptions under some conditions, disorientation stress and/or nausea were not prominent; Vertifuge angular velocity was limited to 1.48 rad/s, which with a 30-deg pitch-up of the cockpit, produced perceived pitch-up attitudes approaching 90 deg in some subjects.

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CONTENTS

SUMMARY PAGE

THE PROBLEM

Disorientation error accidents continue to be a major problem resulting in the loss of experienced Navy pilots and aircraft. The Dynasim's Vertifuge can be used for several purposes such as disorientation demonstration scenarios, evaluation of effectiveness of flight instruments on Vertifuge attitude control during disorienting stimuli, and studies of cognitive and psychomotor performance during disorientation stress. The purpose of the present study was to assess perceptual effects and indications of "disorientation stress" produced by selected stimuli with this device and to provide initial measures of the magnitude of these effects.

FINDINGS

1. Measures of the visual horizontal appear feasible by use of a line of light offset laterally about 25 deg from the subject "dead-ahead" line of regard for perceived pitch angles of ± 90 deg. Despite a substantial g-gradient on the body, the angle of the resultant vector at the subject's head provides a reasonable first approximation of the mean perception of pitch indicated by the visual horizontal.

2. Magnitude estimates of Vertifuge pitch suggest pitch illusions attributable to adaptation effects.

3. Significant problems with motion sickness and/or disorientation stress were not encountered in the stimulus sequence used, despite occurrence of extreme pitch-up perceptions on some trials in the stimulus sequence.

RECOMMENDATIONS

1. The visual display for the visual horizontal estimates should be automated to enable experimenter- or computer-controlled offsets of the display from horizontal and independent resetting or override by the subject.

2. Comparable observations should be carried out at higher stimulus levels and also with the Vertifuge configured to produce pitch-down sensations. Stronger effects and pitch-down perceptions may be necessary for performance-based studies of disorientation stress.

3. Fairly rapid adaptation to a sustained "unusual attitude" is probably a major contributor to covert disorientation. Further study of the apparent adaptation effects suggested in the present observations is recommended to verify their presence. If reproducible in most subjects, such effects would be a valuable addition to demonstrations for purposes of disorientation-prevention training.

Acknowledgments

The authors wish to express appreciation to Mr. Joel Norman for this assistance in running subjects for this investigation and to Mr. W. C. Hixson for suggestions in review of the paper. The authors also wish to acknowledge the typing and report layout skills of S.A. Dasho, and the editorial comments provided by K.S. Mayer.

INTRODUCTION

This is a summary of perceptual responses and disturbance ratings induced by motion stimuli produced by Vertifuge. Shown in Fig. 1, this device is capable of generating large changes in perceived attitude by virtue of pitch or roll motions of the cockpit about secondary axes displaced from the center of rotation. During rotation of the Vertifuge about its main central axis, a pitch or roll motion about a secondary axis introduces both cross-coupled angular acceleration, and changes in direction of the resultant force vector relative to the body. The cross-coupled angular acceleration stimulates the semicircular canals to produce angular velocity sensations and reflexes (e.g., the vestibulo-ocular reflex) orthogonal to angular position change relative to the resultant force sensed by the otolith and somatosensory systems.

The primary purpose of the present observations was threefold: 1) to examine a method of estimating perceived pitch through large arcs, 2) to estimate the disturbing and nauseogenic qualities of stimuli used, and 3) to provide preliminary estimates of perceived pitch under the specific conditions selected for study.

The present observations were restricted to changes in body position in the pitch plane relative to the direction of the resultant force or to gravity with the Vertifuge cockpit facing in centripetal direction. The pitch axis was selected for this initial set of observations because it presents the greater measurement challenge. By various methods used in the past, greater variability has been found in pitch estimates than in roll estimates (1-3). Moreover, the streamlined fuselage and canopy of the Vertifuge limit space available for use of visual indicators of apparent pitch angles greater than ± 10 or 15 deg. Because of the large angles through which perceived pitch can be expected to change during Vertifuge operation, a method was selected that would allow for pitch estimates as great as or exceeding ± 90 deg.

METHODS

APPARATUS

The Vertifuge is a rotary device with a fuselage and cockpit resembling a small aircraft. The center of the base of the cockpit and the pivot point of the pitch axis are at a radial distance of 2.32 m from the main central axis. When the Vertifuge base is level, the center of the headrest, the center of seat, and the center of the footrest are at radial distances of 2.67, 2.32, and 1.45 m, respectively. In this series of observations, the cockpit canopy was black and the only visual stimulus visible to the subject was a line of light 2 mm in width and 12 cm in length, parallel to and displaced laterally 25 deg to the left of the central line of sight; the center of the lighted line was about 49 cm from the eyes. Blackout cloth was used to prevent reflection from the instrument panel. Subjects' heads were maintained with the occiput against the head rest, and the lighted line was viewed by turning the eyes in its direction. The lighted line was pivoted just below its center on the shaft of a precision potentiometer that provided signals proportional to angular displacement of the line from Earth-horizontal.

SUBJECTS

Six subjects, 5 male and 1 female, ranged in age from 23 to 62 years. Two of the subjects were laboratory personnel experienced in the type of experimentation and 4 were student naval aviators.

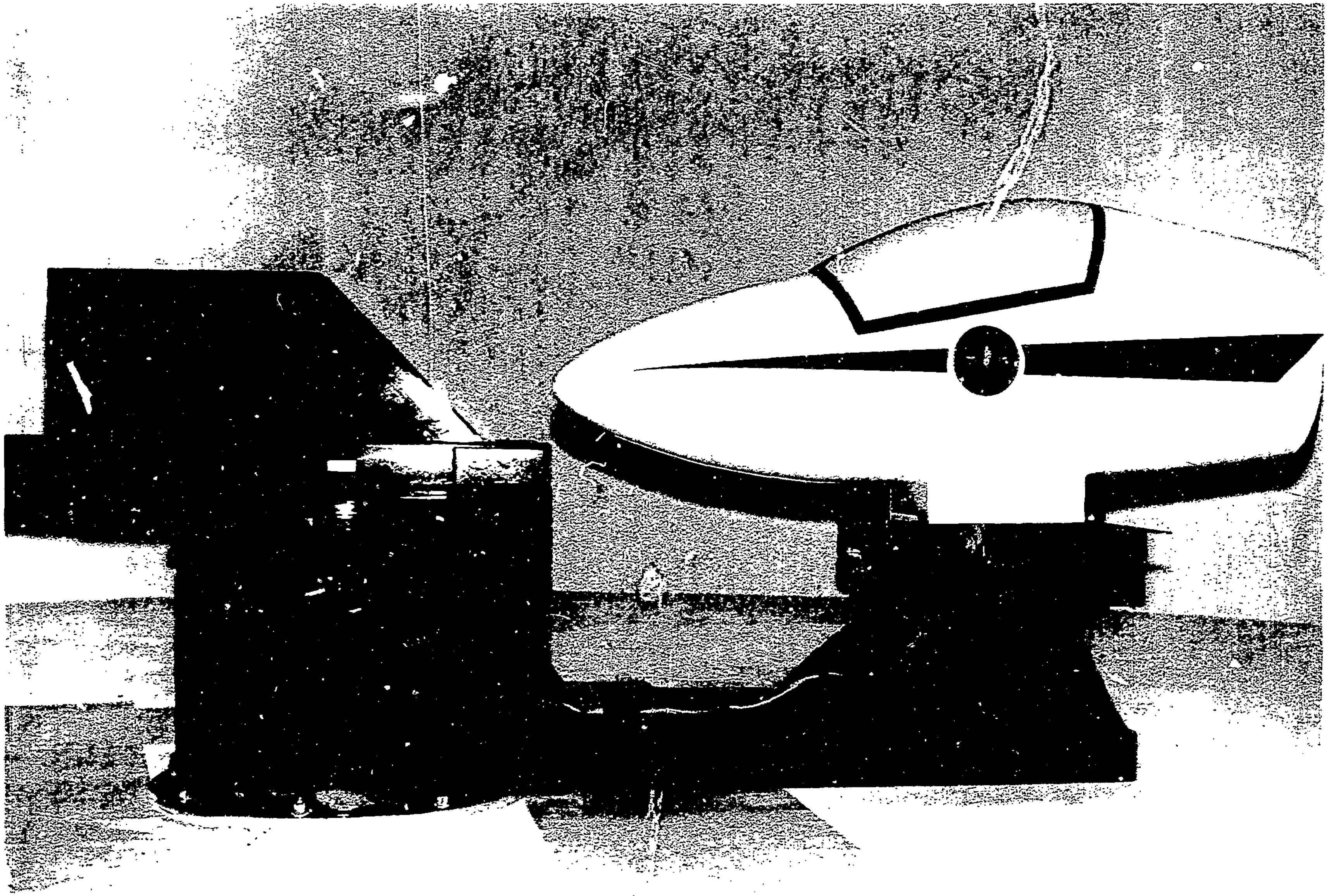

Figure 1. View of the Vertifuge with the cockpit facing in the centripetal direction.

PROCEDURES

The sequence of test trials is shown in Table 1. Except for Trial 1, all trials were commenced by a change in pitch attitude, due either to a change in direction relative to gravity or to the resultant vector. In all trials, the motion of the Vertifuge including changes in pitch were controlled by the Vertifuge operator. On Trials 1, 2, 3, 9, 11, and 14, the Vertifuge was not rotating, but cockpit attitude changes occurred at the beginnings of Trials 2, 3, and 11. Mean angular velocity of each cockpit attitude change was 4.3 deg/s except for those trials in which the attitude change was generated by the angular acceleration or deceleration of the Vertifuge. The Vertifuge was stationary during Trials 9 and 14, but these trials were commenced with deceleration of the Vertifuge from 14.1 rpm (i.e., 1.48 rad/s) to zero velocity at an angular acceleration of 25.6 deg/s^2 (i.e., 0.45 rad/s^2). Therefore, the mean rate of change in the direction of the resultant vector relative to the subject was 9.1 deg/s at the onset of Trials 9 and 14.

TABLE 1. *Listing of Cockpit Positions Relative to Gravity (g) and Relative to the Resultant Vector (A) in Various Trials. Trial 10 Was a 10-min Rest Interval. The Resultant Vector Was Calculated at the Distance of the Subject's Head From the Center For Rotation.*

Trial	Cockpit pitch relative to g (deg)	Cockpit pitch relative to A (deg)	Vertifuge angular velocity (rpm)
1	0	0	0
2	30	30	0
3	0	0	0
4	0	30	accel. to 14.1*
5	-30	-6	14.1
6	0	30	14.1
7	30	65	14.1
8	0	30	14.1
9	0	0	decel. to 0
10	10-min rest	10-min rest	10-min rest
11	-30	-30	0
12	30	65	accel. to 14.1
13	0	30	14.1
14	0	0	decel. to 0

*14.1 rpm = 1.48 rad/s.

The Vertifuge rotated at angular velocity (w) of 1.48 rad/s during Trials 4, 5, 6, 7, 8, 12, and 13. Trials 4 and 12 commenced with an angular acceleration of 9.6 deg/s^2 from 0 to 1.48 rad/s angular velocity (CCW); mean rate of change of the resultant vector was 3.4 deg/s during the angular acceleration. At the beginning of Trial 12 the cockpit was nose-down 30 deg (Θ = -30 deg), but as soon as the Vertifuge attained a constant angular velocity of 1.48 rad/s, the cockpit attitude was changed from -30 to 30 deg relative to Earth-horizontal. Thus, on Trial 12, the entire attitude change required 8.8 s (during angular acceleration)

and almost 14 s during the 60-deg pitch change from -30 to 30 deg relative to gravity. The 65 deg in Column 3 of Table 1 for Trial 12 (and for Trial 7) is due to the increased radial distance of the head when the Vertifuge was pitched up 30 deg relative to gravity.

Subjects had essentially three tasks: 1) to report verbally the perceived change in state of motion during the change and to provide a magnitude estimate of Vertifuge pitch upon request when a "steady state" motion condition had been achieved, 2) to rate feelings of sickness and disturbance (fear) induced by the motion stimuli on a scale of 1-10 where 1 signified no effect and 10 extreme effect, and 3) to make six settings of the line of light to perceived horizontal position during each trial. Six offsets of the line up (U) or down (D) from horizontal, were made per trial according to the prearranged orders "U D D U, U D," or "D U U D, D U."

In the present series of observations, the Vertifuge back support and head support were in full back position, and no effort was made to align the trunk or z-axis of the head (cf. 1,4,5) with gravity when the Vertifuge was stationary and level. This was done in order to assess perception of pitch as the Vertifuge might actually be used in subsequent studies, as opposed to conducting a study of the perception of verticality. In the present observations, when the Vertifuge was level, the trunk was reclined about 15 deg backward, and the Z-axis of the head was pitched backward about 8-10 deg (relative to gravity).

Figures 2-4 illustrate the different "steady state" pitch conditions to which subjects were exposed in this study. The left side (A) in each figure (2A, 3A, and 4A) illustrates actual position of the subject relative to gravity with the Vertifuge stationary (Fig.1). The right side (B) of each figure (2B, 3B, and 4B) illustrate an approximation of the subject's position relative to the resultant force, A, when the Vertifuge was rotating at 1.48 rad/s although the subject's position relative to gravity remained as depicted on the left. The different resultant vectors shown in these figures were calculated from different radial distances of the subject's head from the main axis of the Vertifuge in different trials. This representation of the resultant vector is based upon the assumption that stimulation of the otolith system is a major factor in determining perceived pitch, although the subject's appreciation of his position relative to the Vertifuge certainly enters into judgments such as magnitude estimates of the Vertifuge pitch. In each figure, the straight, dashed line drawn perpendicular to the Vertifuge pitch base plate does not represent part of the apparatus, but is included simply to illustrate the pitch angle of the Vertifuge cockpit relative to the gravity (g) left side) or to the resultant vector, A, (right side). Figure 2A illustrates the "steady state" condition for Trials 1,3,9, and 14; Fig. 2B illustrates Trials 4, 6, 8, and 13. Figure 3A illustrates Trial 2, and Fig. 3B illustrates Trials 7 and 12. Figure 4A illustrates Trial 11, and Fig. 4B illustrates Trial 5.

RESULTS

RATINGS OF SICKNESS AND DISTURBANCES

Only 2 of the 6 subjects gave any indication of sickness as a result of the motion stimuli, and these were slight. One subject indicated a rating of 2 on Trial 5, the first trial involving cross-coupled stimulation, and maintained this rating on each trail until Trials 12 and 13, which were given ratings of 3. However, by Trial 14 the rating had diminished to 2. When questioned, this subject indicated symptoms of sickness were never of a magnitude sufficient for him to have any doubts about his completing the experiment, although he gave a disturbance (fear) rating of 6 on Trial 7 (Trial 7 produced extreme nose-up pitch perceptions). The only other subject who indicated any symptoms of sickness gave a rating of 3 on Trial 13, and this diminished to a rating of 1 (no effect) on Trial 14. Overall, then, this sequence of stimuli induced little or no problem with signs or symptoms of motion sickness, and only 1 subject reported disturbance (fear) as a reaction to maneuvers experienced.

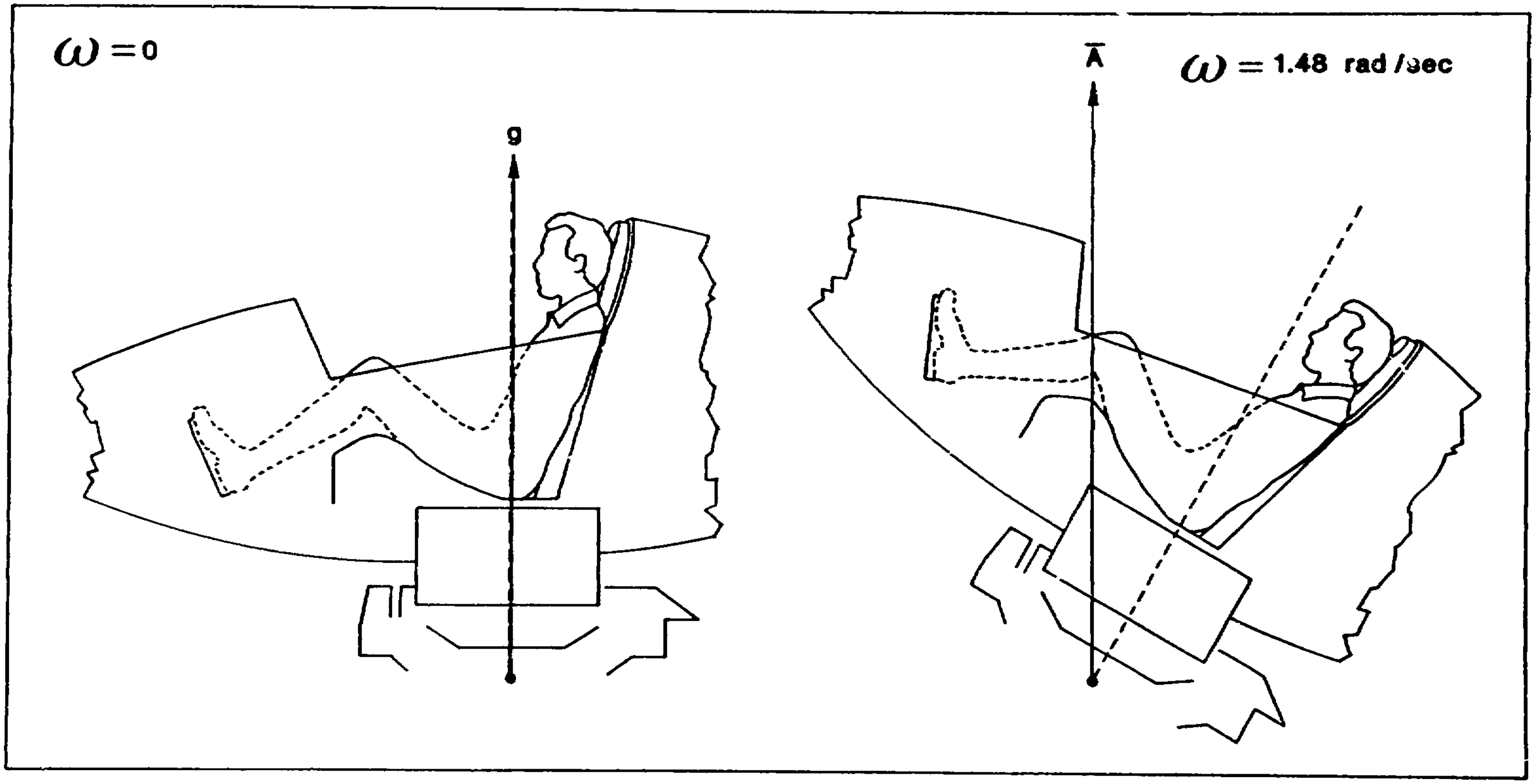

Figure 2. Drawing A illustrates the position of the subject relative to gravity (g) with the Vertifuge in level position (zero pitch) and not rotating (w = 0 rpm), and depicts the "steady state" portion of trials 1,3, 9, and 14. Drawing B illustrates the position of the subject relative to the resultant vector, A, with Vertifuge rotating at an angular velocity of 1.48 radians/s, but subject remained positioned "relative to gravity" as shown on the left, drawing depicts the "steady state" portion of Trials 4,6,8, and 13.

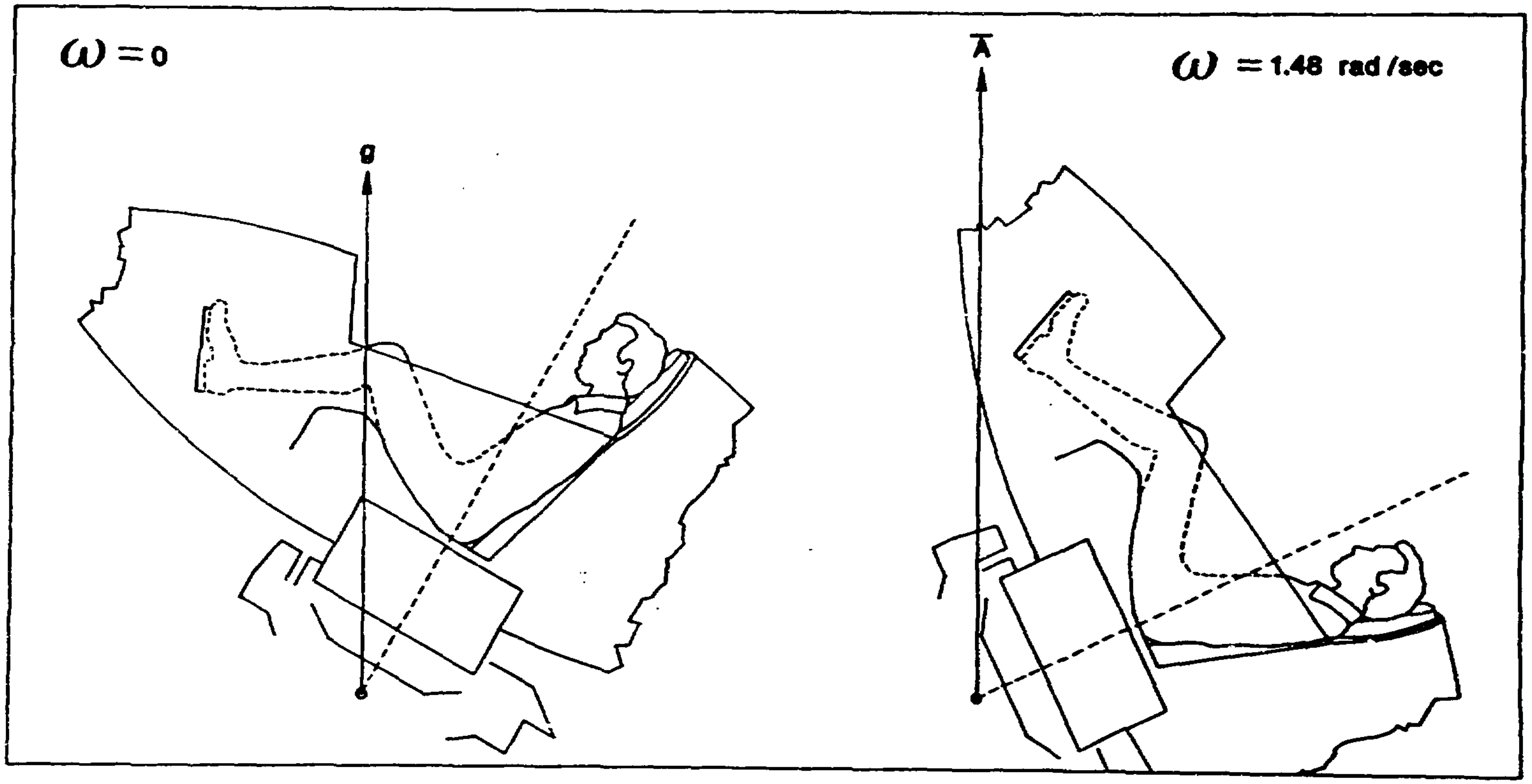

Figure 3. Drawing A illustrates the position of subject relative to gravity (g) with the Vertifuge pitched backward [(0) = 30 deg and not rotating (w) = 0 rpm, drawing depticts the "steady state" position of trail 2. Drawing B illustrates the position of the subject relative to the resultant vector, A, with the Vertifuge rotating at an angular velocity (w) = 1.48 radians/s, but subject remained position relative to gravity as shown on the left, drawing depicts the "steady state" portion of Trails 7 and 12.

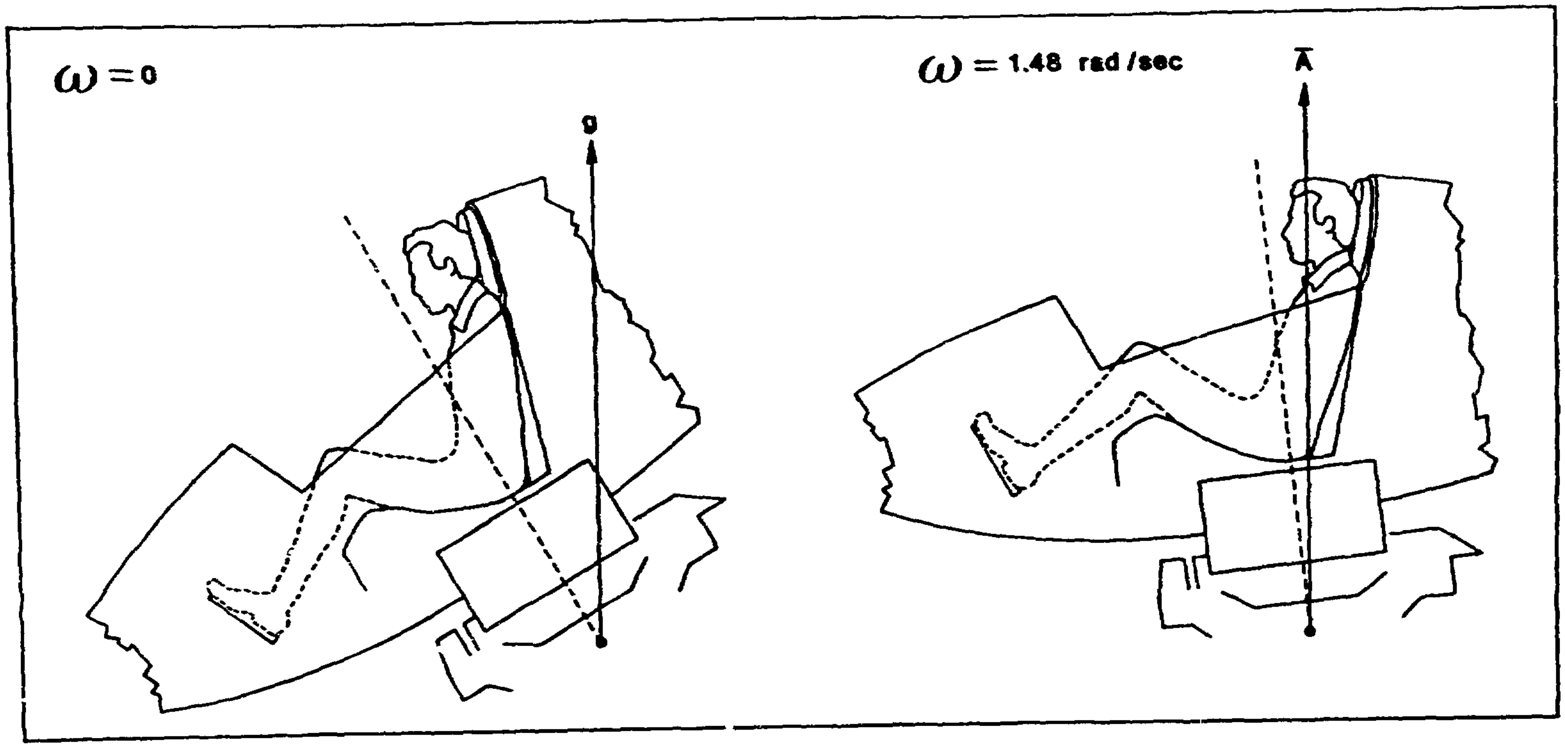

Figure 4. Drawing A illustrates the position of the subject relative to the gravity (g) with the Vertifuge pitched forward [(0) = -30 deg] and not rotating [(w) = 0 rpm], it also depicts the "steady state" position on Trail 11 and position relative to gravity of Trail 5. Drawing B illustrates the position of the subject relative to the resultant vector, A, with the Vertifuge rotating at an angular velocity (w) = 1.48 radians/s, but subject remained position "relative to gravity" as shown on the left, it also depicts the "steady state" position of trail 5, i.e., the position relative to the resultant.

PERCEPTIONS OF TRANSIENTS: VERBAL REPORTS MADE DURING CHANGES IN PITCH

Trials 2, 3, and 11 involved changes in pitch of the capsule while the Vertifuge was stationary. As would be expected, the directions of these changes in pitch angles were accurately reported.

Trials 5, 6, 7, 8, and 13 involved 30-deg changes in pitch of the cockpit while the Vertifuge was at constant angular velocity. In each of these trials, the direction of the change in pitch was accurately perceived but superimposed on this were roll angular velocity sensations in directions that would be expected from effects of cross-coupled stimuli to the semicircular canals. Each of the 6 subjects reported roll sensations as expected from Coriolis cross-coupled stimuli on these trials. Trial 12 commenced with the cockpit in a 30 deg pitch-down position. The Vertifuge was then brought to an angular velocity of 1.48 rad/s so that relative to the resultant force, the cockpit would be nearly "level." At this time the cockpit pitch position was changed from -30 deg to 30 deg. This pitch change of 60 deg required about 14 s and occurred while the semicircular canal response from the preceding angular acceleration was decaying. Although this was the greatest cross-coupled stimulus administered in the experiment, only 1 of 6 subjects reported an unqualified roll sensation, and 3 failed to perceive it at all. This diminished cross-coupled response is almost certainly attributable to the aftereffect of the initial angular acceleration which combines vectorial with the cross-coupled stimulus to yield an angular acceleration aligned approximately with gravity, thereby reducing or under other conditions eliminating (6) the tumbling sensations from the cross-coupled stimulus.

Trial 4 commenced with an angular acceleration of 0.17 rad/s^2 (CCW) to an angular velocity of 1.48 rad/s. Although the cockpit remained level relative to gravity, the resultant of the centripetal acceleration and gravity changed direction relative to the cockpit (and subject) to attain a cockpit pitch-up attitude of Θ = 30 deg. Subjects reported sensations of CCW rotation and increasing pitch-up perceptions as the centripetal acceleration developed. A number of the subjects reported rotation to the right but on being questioned, each of these subjects indicated that he was rotating with right shoulder leading, which signifies counterclockwise (CCW) rotation when subjects are facing centripetally. Thus all subjects perceived a CCW (yaw) angular velocity and a pitch-up attitude during this trial. No subject reported a roll sensation, suggesting that the magnitude of the tangential acceleration (1.45 ft/s^2 or 0.04 g-units) was insufficient to produce a roll perception, although it undoubtedly accounts for the perceived tangential motion with right shoulder leading. Near-threshold linear accelerations are perceived first as linear translation and later as tilt (1).

Trials 9 and 14 commenced with decelerations of 0.45 rad/s^2 from 1.48 rad/s (CCW) to a stop with the Vertifuge in level position through-out. All subjects experienced yaw-right sensations (CW rotation) as would be expected from the semicircular canal stimulus. In addition, 5 of the 6 subjects experienced a dive downward to nose-down attitude on both trials, and the remaining subject reported a brief nose-down effect on Trial 9 but not on Trial 14. Four of the 6 subjects also reported transient roll-right sensations, apparently due to the tangential acceleration (3.8 ft/s^2 or 0.12 g-units) involved in stopping. Thus the average sensation on deceleration from a constant level CCW turn was a diving roll-right clockwise turn. The dive component of the perception may be evidence of adaptation to the preceding nose-up perception that preceded each deceleration.

MAGNITUDE ESTIMATES OF PITCH IN THE "STEADY STATE CONDITION"

Within 10 s after position change had been achieved in each trail, subjects gave a magnitude estimate of pitch. Table 2 summarizes the mean magnitude estimates on each trial.

Perusal of Table 2 suggests two trends in the data: 1) a tendency to overestimate pitch angles, 2) except on certain trials in which adaptation effects may have contributed to underestimates. Except on Trials 4, 8, and 13 pitch angles tended to be overestimated. On Trials 2, 6, 7, 11, and 12, of 30 estimates made, 24 were overestimates of Vertifuge pitch.

TABLE 2. *Mean Magnitude Estimate (ME) of Vertifuge Pitch Made Just After "Steady State" Motion Condition Was Attained. Pitch Angle (0_y) Relative to Gravity (Vertifuge Stationary) or Relative to the Resultant Vector Calculated at the Radial Distance of the Subject's Head During Vertifuge Rotation.*

Trial	Pitch angle 0_y (degrees)	Mean ME	Standard deviation
1*	0	1.0	2.0
2*	30	44.0	10.0
3*	0	-11.0	11.6
4	30	22.0	10.8
5	-6	-11.0	3.2
6	30	41.0	13.0
7	65	84.0	6.7
8	30	12.0	10.8
9	0	-17.0	9.3
10	10-min rest	10-min rest	10-min rest
11*	-30	-40.0	17.0
12	65	74.0	15.6
13	30	16.0	8.0
14*	0	-13.0	8.2

* Vertifuge was stationary in this trial.

Considering the exceptions, Trials 8 and 13 (30-deg pitch-up trials) followed trials involving greater (65-deg) pitch-up angles suggesting that adaptation effects and/or the direction of pitch change served to reduce pitch-up estimates on Trials 8 and 13; 10 of 12 estimates were underestimates on these trials. That adaptation effects influenced estimates of pitch is further suggested by the fact that Trials 3, 5, 9, and 14 (all zero-pitch trials) yielded mean pitch-down estimates of 11, 11, 17, and 13 deg, respectively, and each of these trials followed 30-deg pitch-up trials. On these 4 trials, the subjects made a total of 24 pitch estimates with 22 being pitch-down estimates and 2 being zero-pitch estimates.

Trial 4 is the remaining trail of the 3 trials in which pitch angle was underestimated. This estimate was made during the interval of "lag effect" (7,8), which would yield an underestimate of the pitch angle, assuming that the "lag effect" influences the 'postal' as well as the 'visual vertical.'

This study was not designed to investigate adaptation to sustained pitch; such a study would require additional zero-pitch trials, following a greater variety of antecedent conditions including sustained pitch-down trials. However, adaptation effects following brief periods of sustained pitch (or roll) have been previously reported (1,3,9) and the data obtained are consistent with and adaptive resetting of perceived horizontal during and following sustained pitch-up.

PERCEPTIONS OF PITCH INDICATED BY THE "VISUAL HORIZONTAL"

Figure 5 shows the mean perception of pitch as indicated by settings of the line-of-light by the 6 subjects under the several different pitch conditions. Although each subject made systematic settings of the line proportional to the different angular displacements in pitch, like the group mean data shown in Fig. 5, the slope of the perceived pitch relative to the actual pitch angles differed between subjects (Fig. 6). One subject (#6), in particular, underestimated the 30- and 60-deg pitch angles. Without this subject, the mean pitch-up estimate at the 60-deg position approximates the verbal estimates of pitch. Table 3 presents the mean pitch settings for each trial in the experiment. An overall analysis of variance (ANOVA) for repeated measures on the same subjects indicates highly significant between-trial differences (F (12, 60) = 78.76, p < .01) and also significant between-subject differences (F (5, 60) = 3.96, p < .01).

In Figs. 5 and 6, Trials 1, 3, 5, 9, and 14 were grouped and averaged because each of these trials involved conditions in which the Vertifuge was either level relative to Earth-horizontal (Trials 1, 3, 9, and 14) or approximately level relative to the resultant force (Trial 5). Thus, line settings at or near horizontal were expected for each of these trials. Trials 2, 4, 6, 8, and 13 were also grouped because in each of these trials the Vertifuge was pitched up 30 deg relative to Earth-horizontal (Trial 2) or relative to the resultant force (Trials 4, 6, 8, and 13) and line settings near 30 deg were expected. Results from Trials 7 and 12, which involved approximately 65 pitch-up positions relative to the resultant force, were grouped and averaged.

The results as depicted in Fig. 5 suggest that the angle of resultant of gravity and centripetal acceleration calculated at the radial distance of the subject's head from the Vertifuge main central axis provides a reasonable estimate of perceived pitch. Mean deviations of the line settings from true horizontal (level) were, respectively, 0.4, 0.7, 3.1, and 0.7 deg for pitch angles relative to gravity or the resultant vector of -30, 0, 30, and 65 deg. Thus, the mean line settings averaged over subjects closely approximated mean pitch angles relative to the resultant or to gravity.

However, this close correspondence between pitch angles and line settings indicated by the overall means in Fig. 5 may be somewhat fortuitous in view of: 1) the differences between subjects (Fig. 6), 2) the possibility that there were significant differences between results obtained on Trials 7 and 12 (upon which the 65-deg pitch-up mean was based), and 3) the fact that one of the 30-deg pitch-up trials (Trials 6) appeared to differ from the other 30-deg pitch-up trials (Trials 2, 4, 8, and 13).

An ANOVA on Trials 1, 3, 5, 9, and 14 for repeated measures on the same subjects did not indicate statistical significance between these trials (F(4, 20) = 2.27, p = NS) but between-subject differences were significant (F(5, 20) = 3.27, p < .05). This set of 'zero-pitch' trials yielded a mean adjustment of the lighted line by the 6 subjects to within 1 deg (0.72 deg) of horizontal. There was no clear evidence in these trials of the adaptation effects that were suggested by the data from magnitude estimates of Vertifuge pitch.

Trial 5 involved a 30-deg forward pitch of the Vertifuge to offset the angle of resultant force and yield a near zero-pitch conditions of the Vertifuge relative to the direction of the resultant force. However, forward pitch reduced the radial distance of the subject's head and reduced slightly the centripetal acceleration. Thus, a slight forward pitch perception might have been expected on Trial 5, but this was not apparent in the mean line settings. Figure 4A illustrates the position of the subject relative to gravity, and Fig. 4B illustrates the position of the subject relative to the resultant force on Trial 5. From evaluation of Fig. 4B, the near zero settings are not surprising on this trial; the position of the head and particularly the utricular otolith shear component (cf. 4); a forward pitch perception would not be expected on the basis of either otolithic or postural cues.

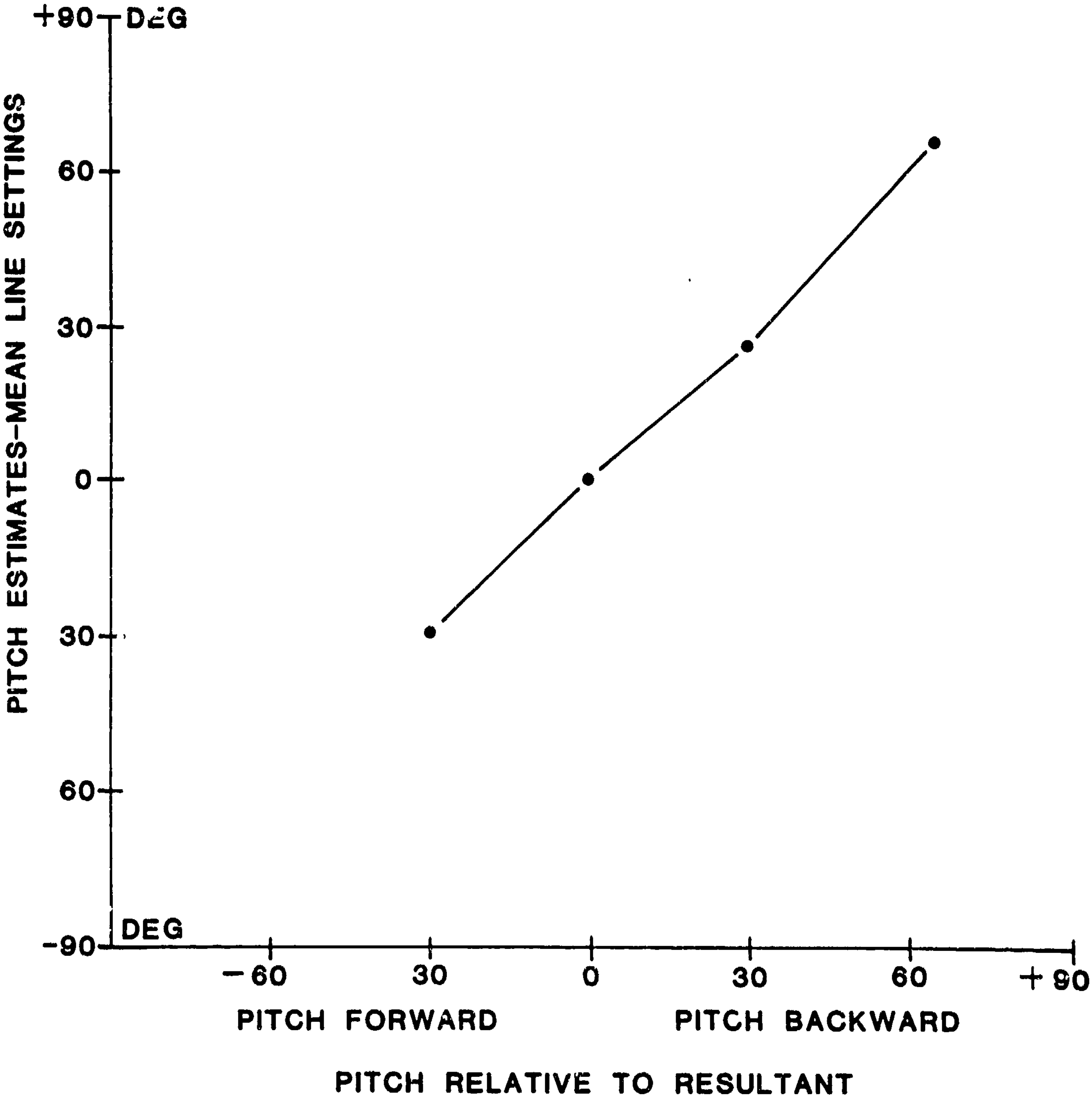

Figure 5. Mean settings of the lighted line averaged over subjects and over sets of conditions yielding pitch angles approximating -30, 0, 30, and 65 deg relative to the resultant vector or gravity.

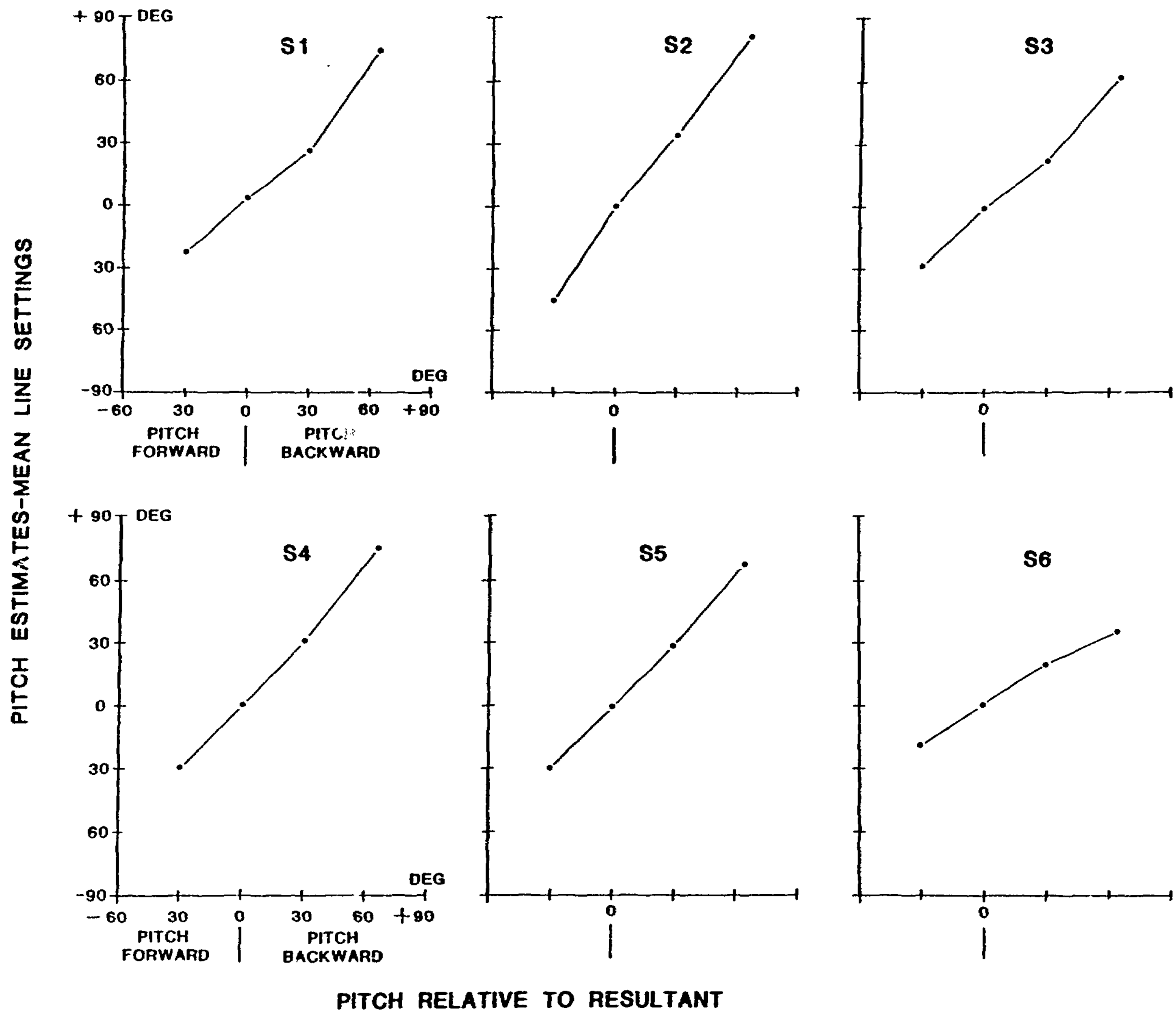

Figure 6. Mean settings of the lighted line by each subject averaged over conditions yielding pitch angles approximating -30, 0, 30, and 65 deg relative to the resultant vector or gravity.

TABLE 3. *Vertifuge Pitch (V) in Degrees Relative to Earth Horizontal, Subject Pitch in Degrees (0) Relative to Gravity (Trials 1,2,3,8,9,13,14) or the Resultant Acceleration (Trials 4,5,6,7,8,11,12,13) and Mean Settings of Line-of-light to Visual Horizontal (VH).*

Trial	Angular velocity (RPM)	Pitch angle (V) (degrees)	Subject angle (Θ) (degrees)	Mean VH	Standard deviation
1	0	0	0	3.0	3.0
2	0	30	30	25.4	6.6
3	0	0	0	-1.0	2.8
4	14.1	0	30	24.1	6.8
5	14.1	-30	-6	0.7	1.7
6	14.1	0	30	32.8	8.0
7	14.1	30	65	70.3	16.3
8	14.1	0	30	25.9	7.5
9	0	0	0	0.1	2.5
10	10-min rest	10-min rest	10-min rest	10-min rest	10-min rest
11	0	-30	-30	-29.6	8.5
12	14.1	30	65	61.1	16.7
13	14.1	0	30	26.4	4.8
14	0	0	0	0.8	3.8

Pitch Angle (V): Vertifuge pitch relative to Earth horizontal.
Subject Angle (Θ): Subject pitch calculated at radius of subject's head.
Mean VH: Mean settings of visual horizontal (6 settings by 6 subjects).

An ANOVA on Trials 2, 4, 6, 8, and 13 for repeated measures on the same subjects indicates that some of the differences between these '30-deg pitch-up' trials may not be attributable to chance (F (4, 20) = 4.25, $p < .05$). As would be expected from Fig. 6, between-subject differences were significant (F (5, 20) = = 10.36, $p < .01$). Inspection of the data reveals only slight differences between these trials except for Trial 6, which yielded generally greater pitch-up estimates than the other trials in this grouping.

The results of Trial 6 are curious. The line settings on Trial 6 consistently exceeded corresponding settings of each subject in Trial 4 (Trial 6 > in 34 or 36 comparisons) and generally exceeded corresponding settings on Trials 8 and 13, all 30-deg pitch-up trials. Other than ordinal position in the session, the only unique aspect of Trial 6 is that it was the only trial in which the cockpit rotated up in pitch 30 deg from a forward pitch bias to attain level position relative to gravity and 30 deg pitch-up relative to the resultant vector while the Vertifuge was in a steady-state rotation condition. On Trials 8 and 13, the cockpit attained a 30-deg pitch-up position by pitch-down rotation of the cockpit from the 65 deg (relative to the resultant) pitch-up position. On Trial 4, 30 deg pitch-up relative to the resultant vector was attained by angular acceleration of the Vertifuge to the angular velocity (1.48 rad/s), which generated the shift in the direction of the resultant vector relative to the Vertifuge.

Under this condition, the "lag effect" (7,8) could be expected to diminish the settings on Trial 4. While this curious result on Trial 6 may be interpreted as a sign of an adaptation effect from Trial 5, this set of 30-deg pitch-up trials considered as a whole does not provide supportive evidence for adaptation effects.

As noted earlier, the final position attained relative to the resultant force in Trial 12 was the same as the final position in Trial 7, and these trials were averaged in Fig. 2. Yet, in Trial 12, 4 of the 6 subjects made verbal estimates of pitch-up, and 5 of 6 subjects made line settings that were less than their pitch-up settings in Trial 7. Line settings made in Trial 7 exceeded corresponding settings in Trial 12 on 32 of 36 settings, and the 4 discrepancies from this apparent consistency were small magnitude reversals. The lesser pitch-up estimates on Trial 12 appear to be statistically significant (sign test, $p < .001$). The 'lag effect' (7,8) may have diminished estimates on Trial 12, an effect that may be attributable to semicircular canal stimulation (out of the pitch plane) associated with the angular acceleration which commenced Trial 12 (cf. 8) followed immediately by sustained cross-coupled stimuli to the semicircular canals. It is also possible that practice or order effects associated with Trial 12, the second exposure to the extreme pitch-up condition, contributed to the difference. Several subjects commented that adjustments of the line-of-light were difficult in the extreme pitch-up condition.

Backward pitch of the Vertifuge fuselage displaced the head and body away from center, thereby increasing the centripetal acceleration and the expected perception of pitch-up on Trials 7 and 12. As calculated at the head, the centripetal acceleration would generate a resultant vector tilted approximately 35 deg relative to the gravity and a total pitch-up attitude of the subject relative to the resultant vector of approximately 65 deg (see Fig. 3B). In Fig. 3B, the subject's back is approximately horizontal and the thighs are approximately vertical relative to the resultant vector. Considering the various somatosensory cues and the position of otolith planes relative to the result force in this trial, it is not surprising that on Trial 7 the subject's mean line setting was 70.3 deg, and the man magnitude estimate was 84-deg pitch-up attitude. As indicated earlier, the mean line settings based upon both Trials 7 and 12 was 65.7 deg, almost identical to the calculated resultant angle.

DISCUSSION

Several judgments were required from subjects in the course of this study. Except for Trial 1, a change in Vertifuge pitch either relative to gravity or relative to A initiated each trial. Verbal descriptions provided by subjects during and immediately after this change in the stimulus yielded results that were generally consistent with perceptions to be expected from analysis of the sensory stimulation that occurred during this transient phase of the stimulus. An exception was the 'dive sensations' that occurred during and after each deceleration of the Vertifuge, possibly attributable to adaptation to the sustained pitch-up condition that preceded each deceleration.

Immediately following achieving the "steady state" pitch position of each trial, subjects, made a verbal magnitude estimate off the pitch condition of the Vertifuge. As indicated in the Results section, these mean magnitude estimates of pitch were underestimates of pitch, suggesting adaptation effects prevailed. Adaptation effects were further suggested in the magnitude estimates by the consistent pitch-up conditions where underestimates of pitch, suggesting adaptation effects prevailed. Adaptation effects were further suggested in the magnitude estimates by the consistent pitch-down mean values obtained at zero Vertifuge pitch following sustained pitch-up conditions. The judgment made during these pitch positions following sustained pitch-up differs fundamentally from the visual horizontal judgments. In the magnitude estimates, subjects were estimating the angular displacement of the Vertifuge away from level attitude. In the visual horizontal estimates, subjects were setting the line to apparent horizontal, a different perceptual judgment, aside from one another (1,2,10). Undoubtedly, configuration of the body within the Vertifuge in the various pitch conditions influences both perceptual judgments, but postural effects may have had differential influence on the two sets of judgments.

aside from one another (1,2,10). Undoubtedly, configuration of the body within the Vertifuge in the various pitch conditions influences both perceptual judgments, but postural effects may have had differential influence on the two sets of judgments.

The methods employed for estimating perceived pitch by manipulating to apparent horizontal a line of light displaced laterally and forward of the head requires a parallax correction in the process of estimating horizontally (or verticality) of the line. Despite the parallax, the various angles of trunk, limbs, and head relative to gravity and the absence of practice trials, the mean settings of the line of light in those trials were close to true horizontal for the various conditions of pitch used. The results suggest that calculation of the angle of the resultant of the centripetal acceleration and gravity at the radial distance of the subject's head provides a reasonable first approximation of the perceived visual horizontal despite the substantial g-gradient (e.g., the radius at the position of the feet and legs is less than the radius at the head).

The trend in the data obtained from the magnitude estimates of Vertifuge pitch is potentially of considerable practical importance. The pitch-down estimates at level position following each 30-deg pitch-up attitude, following the 65-deg pitch-up conditions, appear to be evidence of a postural adaptation effect in which apparent level is reset, an individual attempting to quickly set the Vertifuge to level would presumably move the fuselage to 10-15 deg tail-down attitude. Such adaptation effects have been previously observed (3,8,10) in studies of the postural vertical. In aircraft, the erroneous perception of a pitch-up attitude as <u>level</u> invites a second illusion, overestimation of altitude (11, p. 1109). Under conditions of poor visibility in flight, these illusions in combination increase the probability of a disorientation error accident. The fact that adaptation effects were not revealed in the present observations by the settings of the line of light, that is, the "visual horizontal," is not surprising. Differences between perceived body positions and the setting of visual indicators of horizontal or vertical are a matter of scientific interest (2,12). Passey and Ray (10) did not find adaptation effects in the visual vertical under conditions that produced adaptation effects in the postural vertical.

RECOMMENDATIONS

1. A line of light, offset laterally about 25 deg visual angle to the left of the subject, can be used as a means to obtain estimates of the visual horizontal (or vertical) for conditions yielding perceived pitches of ± 90 deg of the Vertifuge. To ensure the likelihood that judgments are visual (and not partially haptic) and that each judgment is an independent estimate, we recommend that the visual display be automated to enable experiment or computer-controlled offsets and independent resetting or override by the subject.

2. Despite a substantial g-gradient on the subject with the Vertifuge cockpit facing centripetally and rotating, calculation of the resultant vector based upon the radial distance of the subject's head to the main axis of the Vertifuge provides a reasonable first approximation of the mean perception of pitch indicated by the "visual horizontal."

3. In transient conditions involving both cross-coupled stimuli to the semicircular canals and change in orientation of the head and body relative to the resultant force, the perceptions typically reported were combinations of angular velocity (roll) sensations from the semicircular canals and pitch (change in position) sensation generated by the effects of the changing direction of the linear accelerations on the otolith and somatosensory receptors. Thus, at the magnitude levels of stimuli delivered, one system did not clearly dominate over the other. However, semicircular canal stimuli signaling angular motions out of the plane of the changes in the linear acceleration vector may have reduced pitch estimates in some trials.

4. There were no significant problems with motion sickness in the stimulus sequence used; however, only 6 cross-coupled stimuli were administered over a 30-min run. Despite extreme perceptions of pitch-up induced by the angle of the resultant force relative to the subject in some trials (greater than those usually

generated solely by cross-coupled stimuli), subjects generally did not seem to be disturbed by these stimuli. With reservation due to the small N in this study, we recommend that higher angular velocities of the Vertifuge be used in studies investigating performance degradation due to disorientation stress. Also, studies similar to this one should be conducted with the Vertifuge configured to produce pitch-down sensations, which are generally regarded as more stressful that the predominantly pitch-up sensations generated by the Vertifuge configuration used in the present study.

5. Magnitude estimates of pitch attitude provided corroborative evidence of pitch illusions attributable to adaptation effects, which could potentiate disorientation error accidents under certain conditions. Reliability of the production of such effects should be investigated. If they are fairly consistently reproducible, these effects would be a valuable addition to disorientation demonstrations used in training pilots to avoid orientation-error accidents due to covert disorientation.

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